Topic number: 6

Influence of ambient gas temperature on the glow regime of nanosecond repetitively pulsed discharges in air at atmospheric pressure

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Low temperature plasma discharges operating at atmospheric pressure have been receiving a rising amount of attention in recent years. They are studied for an increasing list of applications such as ozone generation, pollution control, biological decontamination, plasma assisted stabilization and ignition of lean flames, flow control and thin film coatings. Among the different types of discharges at atmospheric pressure, nanosecond repetitively pulsed (NRP) discharges are particularly promising.

A detailed experimental study has been carried out on these transient discharges between two pin electrodes separated by 5 mm in a preheated air flow [1, 2]. Synergy effects between successive pulses to create active species (e.g. atomic oxygen) in the flow have been observed. It is interesting to note that the cumulative effect of repeated pulsing achieves steady-state behaviour and then, even if they are transient, the NRP discharges have a visual resemblance with dc discharge regimes. For ambient air temperature of 1000 K the glow-like regime is also observed in a thin voltage range of 6-7 kV [1]. This regime has an emission which fills the gap in a diffuse manner. For voltages higher than 7 kV, the spark-like regime with an intense emission is observed. The measurements show that the glow-like regime is non-thermal and develops through a positive streamer propagating between both electrodes followed by a return wave in the opposite direction. Further details on the experimental results may be found in [1, 2].

In this work, we present a numerical study of the dynamics of NRP discharges based on a 2D axially symmetric fluid model coupling drift-diffusion equations for electrons and ions with Poisson's equation [3]. To take into account the exact shape of the pin electrodes (modeled by hyperboloids) in a rectilinear grid, we have used a Ghost Fluid Method for Poisson's equation [4]. The photoionization is taken into account through the 3-Group SP_3 model [5].

Emissions of streamers mainly consist of band systems from N_2 and N_2^+: the first positive [$1PN_2$, $N_2(B^3\Pi_g) \rightarrow N_2\ (A^3\Sigma_u^+)$] and second positive [$2PN_2$, $N_2(C^3\Pi_u) \rightarrow N_2\ (B^3\Pi_g)$] band systems of N_2, and the first negative band system of N_2^+ [$1NN_2^+$, $N_2^+(B^2\Sigma_u^+) \rightarrow N_2^+(X^2\Sigma_g^+)$]. In laboratory experiments, the emission of streamers at atmospheric pressure and room temperature is dominated by the blue emission of the $2PN_2$, for a comparison with experiments we calculate optical emissions of $1NN_2^+$, $1PN_2$ and $2PN_2$ systems using a model described in [6].

We simulate a single discharge in air occurring during one of the 10 ns long voltage pulses. In order to account for repetitive pulsing and stationary state manner of the repetitive discharge we assume homogeneous preionization in the beginning of the voltage pulse. It was estimated that the density of seed charges in the interelectrode gap is in the order of 10^9 cm^3 for a 10–30 kHz voltage frequency range [4, 7].

To take into account the fact that the discharge occurs at atmospheric pressure in preheated air at temperature T we have changed the value of the total density $N = N_0 T_0 / T$ where N_0 is the density of air at ground pressure and ambient temperature T_0. This means a decrease of the total density by a factor ~ 3 in case of 1000 K compared to 300 K case. Local reduced electric field E/N is then increased by the same factor and thus has a direct impact on transport parameters and reaction rates in air which are assumed to be local functions of E/N. Validity of this approach in the studied range of temperatures is based on Tanaka's work [8].

An example of discharge dynamics for an applied voltage of 7kV during the first 8 ns for an ambient temperature of 1000 K is presented in Fig. 1 as a time sequence of axial profiles of distributions of the electron density and absolute values of the electric field. The propagation of a positive streamer (from right to left) and a negative streamer (from left to right) from the anode and cathode respectively is characteristic for this geometrical (point to point) configuration. Both positive and negative streamers are propagating in the pre-ionization background ahead of both streamer heads. After the interaction of both streamers (after 4 ns) the positive streamer propagates very rapidly towards the cathode in the volume pre-ionized by the negative discharge. Then follows a very fast redistribution of the electric field in the interelectrode gap.

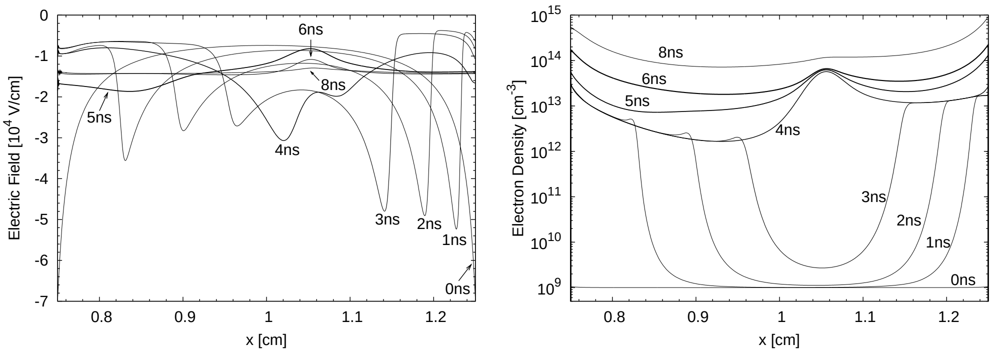

Fig. 1: Electric field (left) and electron density (right) along the axis of symmetry at $t = 0$ to 8 ns, with a timestep of 1 ns.

In this contribution we will present results on the influence of ambient temperature in range of 300–1000 K on the discharge dynamics. The discharge conditions (applied voltage, gap size and radius of curvature of electrodes) in which the glow-like regime can be obtained will be discussed.

Acknowledgements

The authors thank the Agence Nationale de la Recherche for its support of the IPER (grant ANR-05-BLAN-0090-01) and PREPA (grant ANR-09-BLAN-0043-03) projects.

Reference

[1] D. Z. Pai, G. D. Stancu, D. A. Lacoste and C. O. Laux, 2009 Plasma Sources Sci. Technol. 18 045030

[2] D. Pai, 2008 Nanosecond repetitively pulsed plasmas in preheated air at atmospheric pressure, PhD Report, Ecole Centrale Paris, France

[3] S. Celestin, 2008 Dynamics of streamer discharges in air at atmospheric pressure, PhD Report, Ecole Centrale Paris, France

[4] S. Celestin, Z. Bonaventura, B. Zeghondy, A. Bourdon and P. Segur, 2009 J. Phys D: Appl. Phys. Vol 42 No. 6 065203

[5] A. Bourdon, V. P. Pasko, N . Y. Liu, S. Celestin, P. Segur and E. Marode, 2007 Plasma Sources Sci. Technol. 16 565

[6] N. Liu and V. P. Pasko, 2004 J. Gephys. Res. 109 A04301

[7] A. Bourdon, Z. Bonaventura, S. Celestin, 2010 Plasma Sources Sci. Technol., in press

[8] Y. Tanaka, 2004 J. Phys. D: Appl. Phys. 37 851